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Auditory thresholds were obtained for one northern elephant seal (*Mirounga angustirostris*), one harbor seal (*Phoca vitulina*) and two California sea lions (*Zalophus californianus*) under unmasked conditions, masked conditions, and following exposure to noise. Thresholds were determined using a 50% correct detection criterion in a signal detection task using trained behavioral responses to brief pure tones. Results indicate that 1) *Mirounga* is most sensitive to low frequency sounds in water and is relatively hard of hearing in air; 2) *Phoca* has comparable auditory sensitivity to sounds of low frequency in air and under water; 3) *Zalophus* is more sensitive to aerial sounds than underwater sounds; 4) *Zalophus* is susceptible to age related hearing loss, especially at higher frequencies; 5) all three species, and *Mirounga* in particular, are quite good at detecting low frequency signals from noise; and 6) moderately loud underwater sounds have the potential to induce short-term residual hearing loss in all species tested.

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FINAL REPORT

GRANT #: N00014-95-10936

PRINCIPAL INVESTIGATOR: Dr. Ronald J. Schusterman

INSTITUTION: University of California, Santa Cruz

GRANT TITLE: Bioacoustics of Monterey Bay pinnipeds: auditory fatigue and masking

AWARD PERIOD: 1 October 1995 - 30 September 1998

OBJECTIVE: To investigate the aerial and underwater hearing sensitivity of three pinniped species (*Zalophus californianus*, *Phoca vitulina*, *Mirounga angustirostris*) and to determine the effects of noise on hearing.

APPROACH: Auditory thresholds are determined for captive, trained animals using behavioral psychophysical techniques. Thresholds are obtained for three conditions: 1) unmasked (absolute sensitivity); 2) masked (in the presence of octave band noise); and 3) following exposure to noise (20 to 22 minutes of octave-band-noise centered at test frequency).

ACCOMPLISHMENTS: We established a series of low frequency (75 Hz to 6400 Hz) sound detection thresholds in air and underwater for *Zalophus*, *Phoca*, and *Mirounga*. Additionally, we obtained complete aerial and underwater audiograms for *Mirounga*, as well as complete underwater audiograms for a middle-aged *Zalophus* (12-year-old female) and an old *Zalophus* (23-year-old female). These data include the first hearing thresholds of any kind obtained for the deep diving *Mirounga*, and show that *Mirounga* hears extremely well at low frequencies (below 1000 Hz) in water but is relatively hard of hearing in air. Age related losses in hearing sensitivity were documented for *Zalophus* by comparing the two animals tested at mid-range (6000-8000 Hz) to relatively high (16,000-28,000 Hz) frequencies. The hearing deficit in the older animal at the mid-range frequencies was approximately 20dB, and the deficit at the high-range was between 40 and 60dB. Critical ratios, i.e., the amount by which masked thresholds exceed masking noise spectrum levels, were obtained at low frequencies (100 Hz to 2500 Hz) under nearly identical conditions for the three species. These data indicate that pinnipeds in general, and *Mirounga* in particular, are very good at differentiating signals from noise. In the first systematic experiments on underwater temporary threshold shift (TTS) in pinnipeds, hearing thresholds were obtained just prior to noise exposure, immediately following noise exposure, and within 24 hours of noise exposure. Test frequencies ranged from 100 Hz to 2000 Hz, and the octave-band noise exposure levels were approximately 60-75 dB SL (sensation level at center frequency). Each animal was trained to dive into a noise field and remain stationed underwater during a noise exposure period that lasted a total of 20-22 minutes. All subjects showed reliable shifts following noise exposure that averaged about 5 dB, and thresholds recovered to baseline levels within 24 hours. Control sessions, in which the subjects completed a simulated noise exposure, produced shifts that were reliably smaller than those produced following noise exposure. In the field, aerial and underwater

ambient noise levels were recorded at a harbor seal rookery and a northern elephant seal rookery, and acoustic signals were obtained from harbor seal pups, and northern elephant seal mothers and pups.

CONCLUSIONS: With respect to the absolute aerial and underwater hearing sensitivities of the species tested, we determined *Mirounga* to be the most "water-adapted", *Phoca* to be the most "amphibious-adapted", and *Zalophus* to be the most "air-adapted". Furthermore, the data show that elephant seals are most sensitive to sounds of low frequency under water. The critical ratios derived from the masking work for all three pinniped species are similar to those obtained for other marine mammals, and are generally lower than critical ratios obtained for terrestrial mammals. In particular, we are struck by the finding that our single northern elephant seal exhibited the lowest critical ratio of any mammal tested thus far at low frequencies. Reliable TTSs obtained for all three species under water indicate that moderately loud underwater sounds have the potential to cause short-term residual pinniped hearing impairment.

SIGNIFICANCE: These data facilitate prediction of auditory damage to pinnipeds resulting from exposure to noise. All three species are at risk to anthropogenic underwater noise at mid-range frequencies; however, *Mirounga* is at particular risk to low frequency underwater noise (below 1 kHz). With respect to airborne sound, *Zalophus* is particularly at risk to a range of frequencies (4-28 kHz), followed by *Phoca*. *Mirounga* is at little risk to aerial anthropogenic noise, because this species is generally hard of hearing throughout its entire aerial hearing range. The finding of age related hearing loss in *Zalophus* parallels findings in human subjects, in that sensitivity to higher frequencies is lost to a much greater extent than sensitivity to the lower frequencies. The masking data suggest that pinnipeds are efficient at extracting signals from ambient noise, even through they lack sonar. Field studies of ambient and biological noise is consistent with our lab work showing that *Mirounga* is relatively hard of hearing in air compared to *Phoca*.

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